bulletins and the like publications, seemingly the most satisfactory basis of classification is that of geographic origin, according to which two main groups suffice, "Tropical" and "Extratropical."

Tropical cyclones of greater or less intensity possess characteristics which differentiate them, in a measure, from cyclones of extratropical origin having approximately equal intensities, yet the essentials of both groups are practically the same.

Hurricane; Typhoon.—Special terms have been employed to designate tropical cyclones in various parts of the world, especially when fully developed and exhibiting destructive intensity. The word "cyclone" was first applied to violent disturbances of cyclonic character in the Bay of Bengal; but to a similar disturbance originating 1,000 to 2,000 miles to the eastward, as in the China Sea or the region of the Philippines, the name "typhoon" is frequently applied. In the tropical seas to the southeastward of the North American Continent the name "hurricane" is applied, and this disturbance is given the additional qualifying words "West Indian," evidently to indicate its location or place of origin.

In Weather Bureau usage, therefore, the name "West Indian Hurricane" is specifically applied to fully-developed tropical cyclones which originate and exhibit destructive violence in the West Indies or adjacent regions. A West Indian hurricane can cause great damage because of wind effects, because of great volumes of precipitation, by unusual tidal conditions, or by combinations of these and other accompanying characteristics. The word "hurricane" is also used in other combinations, and then has a different signification. For example "hurricane" is the highest force on the Beaufort wind scale. Winds of "hurricane force" are considered to have actual velocity of 75 miles per hour or more, and winds attaining such speed are said to blow with hurricane force, irrespective of geographic locality or whether the winds are associated with a cyclone of West Indian origin.

Tropical cyclones of the West Indies, as well as of other portions of the Tropics, occasionally pass into extratropical regions. The question may then be asked, "How shall a tropical cyclone or a West Indian hurricane or a typhoon be classed after it has passed into extratropical latitudes"? Tropical cyclones change in important particulars when they leave the warm, humid equatorial regions and come under the influence of conditions prevailing in the Temperate Zone. Such changes, however, take place gradually, and a tropical cyclone may show great intensity even several degrees north of the Tropic of Cancer, especially when traveling over water. While moving inland over the North American Continent, however, they show marked signs of waning intensity and soon become indistinguishable from cyclones of actual extratropical origin.

In a bulletin issued by the Weather Bureau, entitled "The West Indian Hurricane of August 13–23, 1915," the track of that great storm is shown from its first appearance in the vicinity of Martinique to its practical dissipation in the Gulf of St. Lawrence.[1] While in a connection of this character the term "West Indian hurricane" may be appropriately applied to this great storm at any point of its course, nevertheless to do so does not in that case necessarily imply that at every point of its path the storm exhibited destructive violence. Similarly, throughout its course the storm may properly be designated a "tropical cyclone," as the observations available show its tropical origin. In the absence of such knowledge the same storm in temperate latitudes would be named an "extratropical cyclone."

[1] Also on chart XLIII—92 of the present issue of this issue of the REVIEW—C. A., jr.

Tornado.—This name is applied to certain storms of well-known characteristics. While they occur in connection with certain cyclonic systems and exhibit great intensity, they are, nevertheless, of extremely local geographic extent and of very short duration.

NOTE ON THE CRUSHING OF A COPPER TUBE BY LIGHTNING.

By W. J. HUMPHREYS, Professor of Meteorological Physics.

[Dated: Weather Bureau, Washington, D. C., Sept. 1, 1915.]

Introduction.—Although the collapse of a hollow lightning rod under the stress of a heavy discharge has already been described and explained,[1] the phenomenon appears to be of unusual occurrence and not very generally known. It may, therefore, be worth while to discuss in some detail an excellent example of a crushed lightning conductor kindly furnished for this purpose by Mr. West Dodd, of Des Moines, Iowa.

In a letter dated April 5, 1915, Mr. Dodd, referring to the conductor in question, says:

> The crushed tube was 5 feet long. It constituted the entire part that stands on top of the house for the point.
>
> The rest of the rod was copper cable and about 50 to 100 feet of that was crushed into smaller volume or made smaller in diameter, as it was loosely woven.
>
> This happened in Michigan about six years ago, and the house was not damaged any—not even a splinter taken off.
>
> Similar phenomena of this kind have occurred in four or five instances to my knowledge, but in the great majority of cases where a point is melted the tube is not damaged.

An additional reason for discussing this particular example of the effect of the "pinch phenomenon"[2] is the fact that it offers data sufficient for making a rough estimate of the current strength of the discharge, and even a crude estimate of the quantity of electricity involved.

Description of conductor.—Figure 1 shows two originally duplicate (so reported), hollow, copper lightning rods, one uninjured (never in use), the other crushed by a discharge. The uninjured rod consists of two parts, shown assembled in figure 1 and separate in figure 2. The conical cap, nickel plated to avoid corrosion, telescopes snugly over the top of the cylindrical section, and when in place, where it is left loose or unsoldered, becomes the ordinary discharge point.

The dimensions are:

Section.	Outside diameter.	Inside diameter.
	Millimeters.	*Millimeters.*
Cylinder	16.0	14.65
Cone shank	17.4	16.0

Length of conical cap, cylindrical portion, 7 cm., total, 19 cm.

Both the cylindrical and the conical portions of the rod are securely brazed along square joints.

Effects of discharge.—The general effects of the discharge, most of which are obvious from the illustrations, were:

1. One or two centimeters of the point were melted off.

[1] *Pollock & Barraclough.* Jour.-Proc., Roy. soc., N. S. Wales, 1905, **39:** 131.

[2] For the origin of this term, now widely used, and a general discussion of the phenomenon, see *Northrup*, Phys. Rev., 1907, **24:** 474; Trans., Amer. electrochem. soc., 1909, **15:** 303.

[To face p. 396.

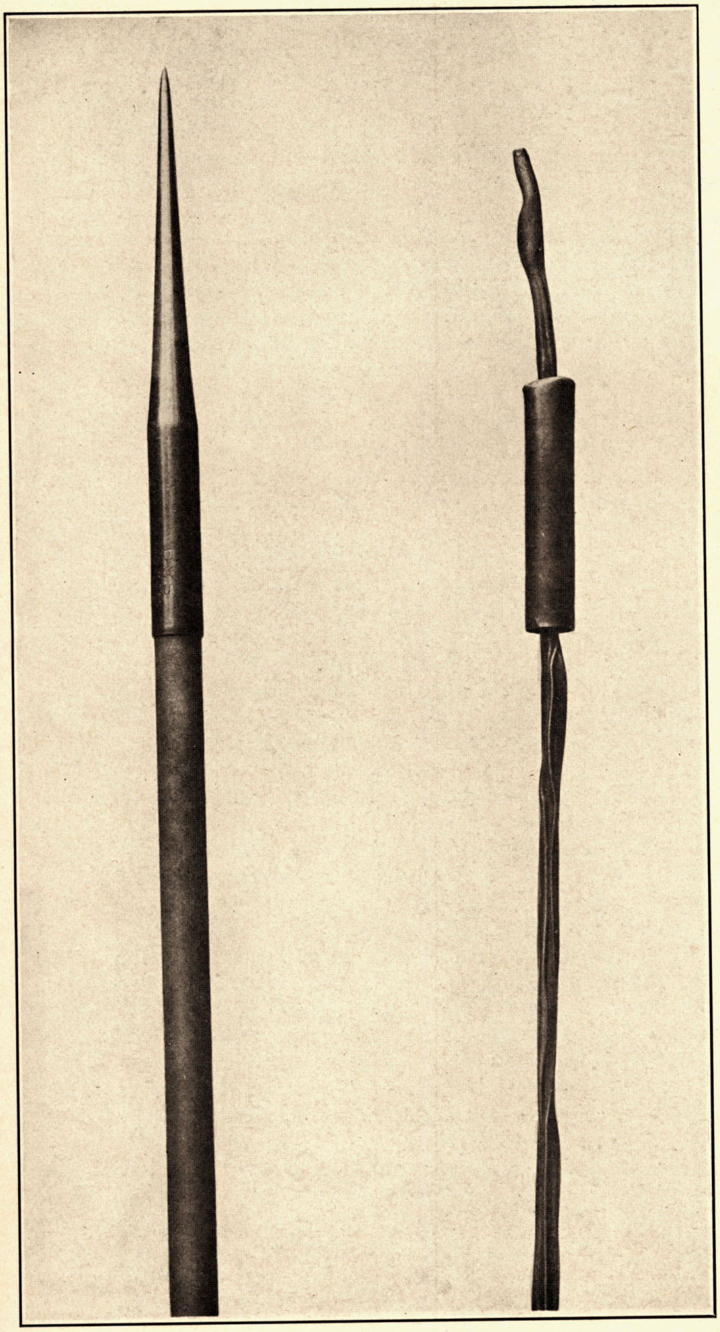

FIG. 1.—Originally duplicate hollow copper lightning rods. Rod on the left never in use; rod on the right crushed by a lightning discharge.

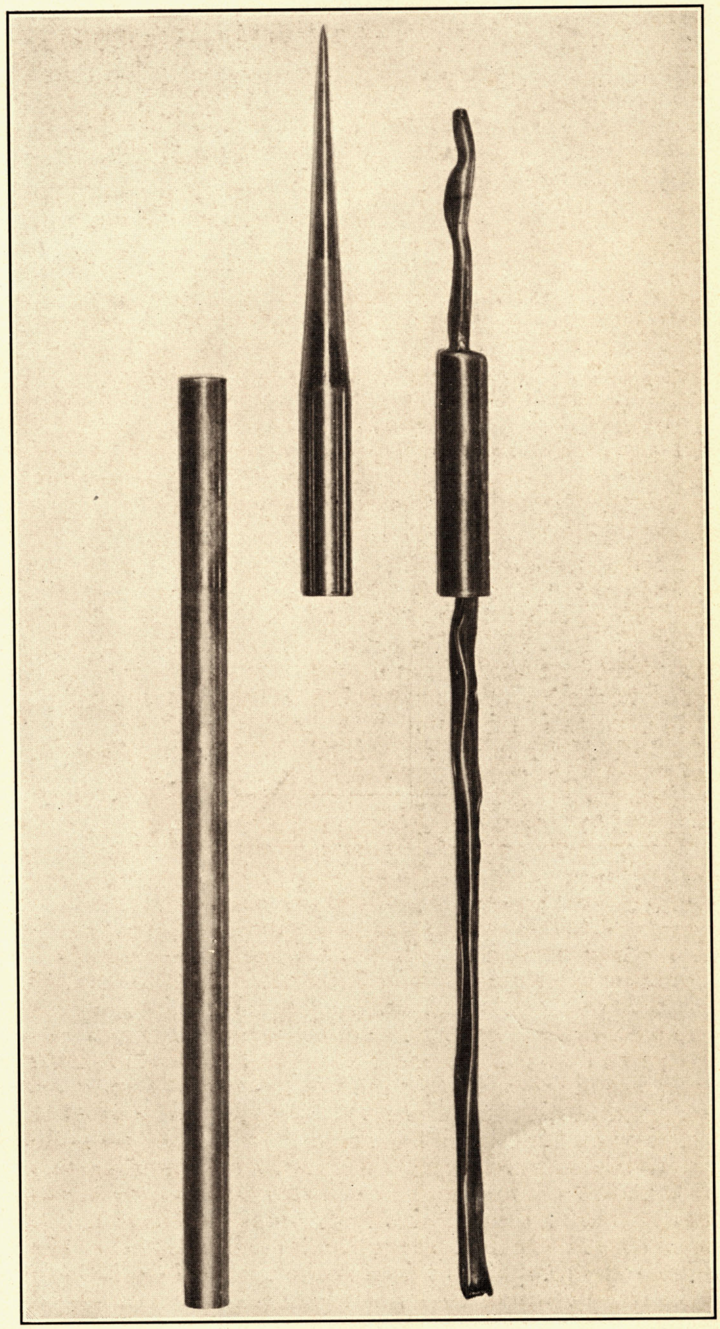

FIG. 2.—Originally duplicate hollow copper lightning rods shown in figure 1, but not assembled.

2. The conical portion of the top piece and all the cylindrical rod except the upper 2 centimeters, roughly, within the cap were opened along the brazed joint.

3. The brazing solder appears to have been fused and nearly all volatilized, as only patches of it remain here and there along the edges.

4. The upper end of the cylindrical rod was fused to the cap just below its conical portion.

5. The rod was fused off where it passed through a staple. Whether a bend in the conductor occurred at the place of fusion is not stated.

6. The collapse of the cylindrical rod extended up about 5 centimeters into the cap.

7. The cylindrical portion of the cap, about 7 centimeters in length, was uninjured; even the brazing was left in place.

Cause of collapse.—What force or forces caused the collapse of the rod? Possibly it might occur to many that it was produced by the reaction pressure from an explosionlike wave in the atmosphere, due to sudden and intense heating. But however plausible this assumption may seem at first, there, nevertheless, are serious objections to it, some of which are:

1. While explosions with their consequent pressure may be obtained by passing a powerful current along a conductor, they seem to occur only on the sudden volatilization of the conductor itself, which in this case did not take place.

2. The heating of the air inclosed by the rod should have produced a pressure from within more or less nearly equal to the pressure simultaneously caused from without, and thereby have either prevented or at least greatly reduced the collapse.

3. The assumption that the crushing of the conductor was due to mass inertia of the suddenly heated air offers no solution whatever of the collapse of the portion of the rod within the shank of the cap.

For these reasons the idea that the collapse of the conductor may have been caused by the reaction pressure of an explosion wave in the atmosphere due to sudden heating, seems to be untenable.

Probably the explanation of the collapse already offered by Pollock and Barraclough at least involves an important factor, if it is not wholly correct. It is as follows: Each longitudinal fiber, as it were, of the conductor attracted every other such fiber through the interaction of the magnetic fields due to their respective currents, and the resulting magnetic squeeze on the hollow rod, whose walls were weakened by the heating of the current, caused it to collapse as shown in figures 1 and 2 opposite.

As is well known the force f in dynes per centimeter length, with which a straight wire carrying a current of I amperes is urged at right angles to the direction of the lines of force of a uniform magnetic field of intensity H, is given by the equation,

$$f=\frac{IH}{10}.$$

Also the value of H at a point r centimeters distant from a relatively very long straight conductor carrying I amperes, is given by the relation,

$$H_r=\frac{2I}{10r}.$$

Now, as developed by Northrup[3] in the theory of his heavy-current ammeters: let a, figure 3, be the outer and b the inner radius of a tubular conductor, and let r be the radius of any intermediate tube of infinitesimal thickness, dr. Also let the conductor as a whole carry a uniformly distributed current of I amperes. Then the value of the magnetic force, at the end of the radius r, is given by the equation

$$H_r=\frac{2I(r^2-b^2)}{10r(a^2-b^2)},$$

which depends upon the fact that only those portions of the current less than r distant from the axis are effective—the forces due to the outer portions neutralizing each other. Also the strength of the current dI, carried by the cylinder of radius r and of infinitesimal thickness dr, is given by the relation,

$$dI=\frac{2Irdr}{(a^2-b^2)}.$$

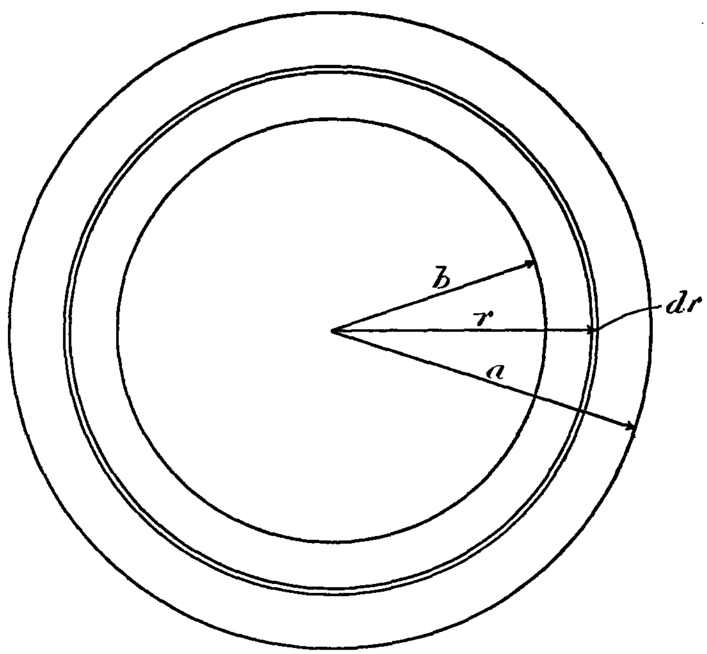

FIG. 3.—Section of a tubular conductor, of outer radius a and inner radius b; r, radius of any intermediate tube of infinitesimal thickness, dr. The conductor as a whole carries a uniformly distributed current of I amperes.

Hence under the assumed conditions, the normal pressure, dP, per unit area on the cylinder of radius r and thickness, dr, may be determined by the equation,

$$dP=\frac{2Irdr}{2\pi r10(a^2-b^2)}\times\frac{2I(r^2-b^2)}{10r(a^2-b^2)}.$$

Hence the total normal pressure, P, per square centimeter of the *inner* surface is given by integrating the above expression between the limits b and a. That is:

$$P=\frac{2I^2}{100\pi(a^2-b^2)^2}\left(\int_b^a r\,dr-b^2\int_b^a\frac{dr}{r}\right)$$

$$=\frac{2I^2}{100\pi(a^2-b^2)^2}\left[\tfrac{1}{2}(a^2-b^2)+b^2\log_e\frac{b}{a}\right]$$

$$=\frac{I^2}{100\pi(a^2-b^2)}\left(1+\frac{2b^2}{a^2-b^2}\log_e\frac{b}{a}\right).$$

[3] Trans., Amer. electrochem. soc. 1909, 15:303.

Substituting for a and b their numerical values, 0.8 cm. and 0.7325 cm., respectively, it is found that,

$$P=\frac{I^2}{379.1}.$$

If we assume P, the pressure in dynes per square centimeter of the inner surface to be 10^6 or approximately one atmosphere, then $I=19{,}470$ amperes, approximately.

If the lightning discharge were alternating the current density would be greatest in the outer portions of the conductor, and therefore the total current would have to be still heavier than the above computed value to produce the assumed pressure. However, it seems probable that the discharge is unidirectional and not alternating,[4] and therefore that the computed strength of current, though of minimum value, is substantially correct.

Estimated charge and strength of current.—To determine the amount of electricity involved in a lightning discharge it is necessary to know both its duration and the average strength of current. Both factors and, therefore, the total charge are known to vary greatly, though actual measurements have been comparatively few and even these, as a rule, only crudely approximate.

It has often been stated that the duration of a single discharge, or single component of a multiple discharge, is not more than 1/1,000,000 of a second. Some have computed a duration of roughly 1/100,000 of a second, while others have estimated that it can not be greater than 1/40,000 or, at most, 1/35,000 of a second. Possibly many discharges are as brief as some of these estimates would indicate, but there is ample reason to believe that others are much longer. Thus one occasionally sees a streak of lightning that lasts fully half a second without apparent flicker, while more or less continuous or ribbon discharges are often photographed by moving cameras. But in addition to these evidences we have also a number of time measurements made by Rood[5] with a rotating disk, ranging from less than 1/1,600 second up to 1/20 second, and others, 38 in all, by De Blois[6] with an oscillograph, ranging from 0.0002 second to 0.0016 second. In one case De Blois found the durations of five sequent discharges to be 0.0005, 0.0015, 0.0016, 0.0014, and 0.0012 second, respectively, or 0.0062 second as the summation time of these principal components of the total discharge. Hence it seems probable that the actual time of a complete discharge, that is, the sum of the times of the several components, may occasionally amount to at least 0.01 second.

The second factor, the strength of discharge, is even more difficult to determine, and but few estimates of it have been made. Pockels,[7] adopting the ingenious method of measuring the residual magnetism in basalt near a place struck by lightning and comparing these quantities with those similarly obtained in the laboratory, concluded that the maximum strength of current in such discharges amounted occasionally to at least 10,000 amperes. However, the loss of magnetism before the measurements were made, and other unavoidable sources of error, indicate that the actual current strength was much greater than the estimated value—that the maximum strength of a heavy lightning discharge certainly amounts to many thousands of amperes, occasionally perhaps to even one hundred thousand.

[4] *Humphreys*, MONTHLY WEATHER REVIEW, June, 1914, **42**: 377.
Marvin, idem, August, 1914, p. 499–501.
[5] Amer. jour. sci., 1873, **5**: 163.
[6] Proceedings, Am. inst. elec. eng., 1914, **33**: 568.
[7] Annalen d. Phys., 1897, **63**: 195; 1898, **65**: 458; Met. Ztschr., 1898, **15**: 41; Phys. Ztschr., 1901, **2**: 306.

Since the above estimates are very rough it would seem well to check them, even though the check itself be equally crude. Hence it may be worth while further to consider the crushed lightning rod with this particular object in view.

From the dimensions of this rod, outside diameter 1.6 cm., inside diameter 1.465 cm., it follows that its cross-sectional area is about 0.325 sq. cm., and its weight, therefore, approximately 2.9 grams per centimeter. Further, from the fact that the brazed joint was opened and most of the solder removed—apparently volatilized—and the further fact that the condition of the rod itself in several places indicates incipient fusion, it would seem that the final temperature may have been roughly 1,050°C. If so, the rod must have been heated about 1,025° C., since its temperature just before being struck probably was approximately 25°C. But the average specific heat of copper over this temperature range is roughly 0.11, and therefore about 327 calories per centimeter were generated.

Now one ampere against one ohm generates 0.24 calories per second. Hence, since the resistance[8] of the uninjured or check rod is practically that of pure copper, the average resistance of the crushed conductor over the assumed temperature range probably was about 17 microhms per centimeter length,[9] we have the equation,

$$\frac{24}{10^2}I^2\frac{17}{10^6}t=327,$$

in which I is the average strength of current, and t the actual time of discharge. Assuming $t=0.01$ second we get, roughly,

$$I=90{,}000 \text{ amperes.}$$

A current of this average value would indicate a maximum value of perhaps 100,000 amperes.

It was computed above that a current of 19,470 amperes in the given hollow conductor would produce on it a radial pressure of 10^6 dynes per square centimeter or about one atmosphere. Hence 100,000 amperes would give a pressure of 2638×10^4 dynes per square centimeter, or approximately 400 pounds per square inch; enough, presumably, to produce the crushing that actually occurred.

A current of 90,000 amperes for 0.01 second would mean 900 coulombs, or 27×10^{11} electrostatic units of electricity; certainly an enormous charge in comparison with laboratory quantities, but after all a surprisingly small amount of electricity, since it would electrolyze only 0.084 of a gram of water. It must be clearly kept in mind, however, that these estimates are exceedingly rough and that at most they only tend to confirm certain previous estimates in regard to the lightning discharge, namely, that in some cases the strength of current probably amounts to many thousands of amperes, and that the total duration of the individual or partial discharges may be several thousandths of a second.

A NOTE ON THE RELATION OF CLIMATE TO AGRICULTURE IN CALIFORNIA.

By ANDREW H. PALMER, Observer.

[Dated Weather Bureau, San Francisco, Cal., Aug. 1, 1915.]

It has been remarked that in the climatic conditions affecting agriculture California shows an epitome of the whole United States, with added climatic characters peculiarly her own. Indeed the statement might have

[8] Measured by the U. S. Bureau of Standards.
[9] *Northrup*, Jour. Franklin inst., 1914, **177**: 15.